DEVELOPMENT OF A SMALL SATELLITE SERIES ISRO EXPERIENCE

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Abstract

The development of a small Stretched Rohini Satellite Series (SROSS) in the Indian Space Research Organisation (ISRO) has moved hand in hand with that of one class of indigenous launch vehicles, the Augmented Satellite Launch Vehicle (ASLV). In other words, these satellites have been developed as compatible payloads for those launch vehicles. The first two satellites, SROSS-1 and SROSS-2, although were very versatile satellites carrying space science related payloads could not be orbited owing to failure of launch vehicles. The third satellite in the series, SROSS-C, was a smaller satellite launched by the third developmental flight ASLV-D3 on May 20, 1992. Earlier, the 40 Kg class Rohini Satellites (RS) were developed as payloads for the smaller launch vehicles (SLV-3) during the pre-eighties, which were suitably augmented to the Augmented Satellite Launch Vehicles to carry the 150 Kg class Stretched Rohini Satellite Series during the pre- & post-nineties. This new satellite series were configured on the basis of a common bus concept, which are extremely compact, cost effective as well as innovative. It is compact because subsystems are very densely packed, cost effective because the bus is common and hence easily reproducible, and innovative because it is modular and hence easily reconfigurable. The paper describes some of these important aspects giving full narration of the development including pre-launch, launch and on-orbit operations of SROSS-C in detail.

1. INTRODUCTION

Aryabhata was the first satellite built and operated by ISRO as a technological venture in order to gain first hand experience in the high technology area of space. After gaining sufficient confidence from Aryabhata, subsequent thrust for development was given in two definite directions, viz., Remote Sensing and Communication as far as satellite development was concerned. Bhaskara-1, Bhaskara-2 & APPLE Satellites were developed and experimented. Almost at the same time, high thrust was also given for the development of ISRO's own launch vehicles in order to achieve self-reliance in field of space. This was where it was rightly thought to develop small, inexpensive but innovative satellites as payloads for those launch vehicles to cater to the needs of scientists and experimenters engaged in the field of space science and space research. Thus the SROSS satellites were configured to carry space science payloads for space scientists, space technology payloads for space technologists and space application payloads for space futurists. By now, of course, ISRO has entered into the operational era with IRS and INSAT series of satellites. Nevertheless small satellites have a distinct place in ISRO's current profile of space ventures.

The global interest in small satellites is undoubtedly due to the rapid progress in the usage of microelectronic devices, simplified software techniques and high frequency bands which is responsible for substantial reduction in size, weight and power of the space hardware. Notwithstanding the above fact, the volume of data the satellite need handle and/or the orbit the satellite need be placed in, finally decide the size of the satellite. New concepts however are creeping in to overcome some of these constraints by means of multiple satellite by descent from the Geo Stationary Orbit (GSO) to the Lower Earth Orbit (LEO). This has further deepened the interest in making small satellites as a very cost effective measure and in this context the SROSS satellites provide a unique insight into design, development, fabrication, testing and on-orbit operation of small satellites.

2. SROSS PROGRAMME

The SROSS programme envisages to place four to five small 150 Kg class satellites in low earth 400 KM circular orbits at 45.6 degree inclination for gainful purposes in the areas of space science, technology and application. In the first place, this satellite serves as the payload for our developmental launch vehicle, ASLV. Secondly, it flight proves all our new technologies for future operational satellite missions. Thirdly, it is configured in order to carry out various space science related missions using the same common bus. For example, SROSS-1

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was conceived to be a 3-axis stabilised LEO satellite, which would monitor the developmental launch vehicle parameters, conduct Gamma Ray observations from space, and also facilitate ranging using retro reflectors. SROSS-2 was conceived to observe Gamma ray sources using only one detector and take stereoscopic images of the earth using a monocular electro-optical stereo scanner (MEOSS) developed by the DLR, West Germany. Owing to the successive failures of launch vehicles, SROSS-C was conceived to be a simple spinner satellite in order to conduct experiments both in the areas of Astronomy using Gamma Ray Burst detectors and Aeronomy using Retarding Potential Analysers. SROSS-C2 is conceived to carry out similar missions in space with the inclusion of the Reaction Control System (RCS) for orbit manoeuvres.

3. DESIGN OF SROSS BUS

The spacecraft size is restricted by two factors, the dynamic envelope of ASLV heat shield and its volume(Fig.1). This gave rise to an octagonal prismoidal shape of the satellite for generation of maximum onboard power with a dimension of 820 mm across flat surfaces and a height of 1100 mm. Consequently the Moment of Inertia (MI) about the lateral axes were higher than that about the longitudinal axis, giving rise to another important consideration of spacecraft stability in orbit, since the satellite is spun about its longitudinal axis at 135 rpm at the time of separation. In order to facilitate quicker stability of the satellite in orbit, the process of flat spin is aided by firing of thrusters for despin.

As mentioned earlier, the configuration of the spacecraft is based on a common bus concept primarily to minimise the turn around time of building two consecutive satellites. Also the spacecraft bus or mainframe is designed so as to support both 3-axis as well as spin stabilised satellites in orbit, for which inclusion of a momentum wheel is essential. This has further complicated the matter by forcing the configuration to go for deployable solar panels in order to cater to the enhanced power requirement by similar order of magnitude.

The overall configuration of the spacecraft is chosen such that a versatile SROSS bus is evolved for at least a decade in order to carry out various space science related experiments using the same bus. Basically the satellite bus is divided in three major compartments. The compartment accommodates the RCS tank at its centre and other accompanying accessories at peripheries. The middle compartment accommodates the battery at its centre. The top deck is meant for the payload systems alone. There are thus two horizontal octagonal decks and two vertical rectangular decks to support all the main frame systems. There is a conical adaptor with a circular flange at the bottom to interface with the launcher separation ring. Fig. 2 shows the exploded view of the structure.

The whole structure is made up of proven aluminium honeycomb decks and panels held to a central riveted frame made out of forged and machined solid aluminium parts. The structural design provides a low natural frequency of 21 Hz in the lateral direction and 72 Hz in the longitudinal direction. The spacecraft is so compact that the accessibility for any repair or rework is quite limited. It has one of the highest density of packing.

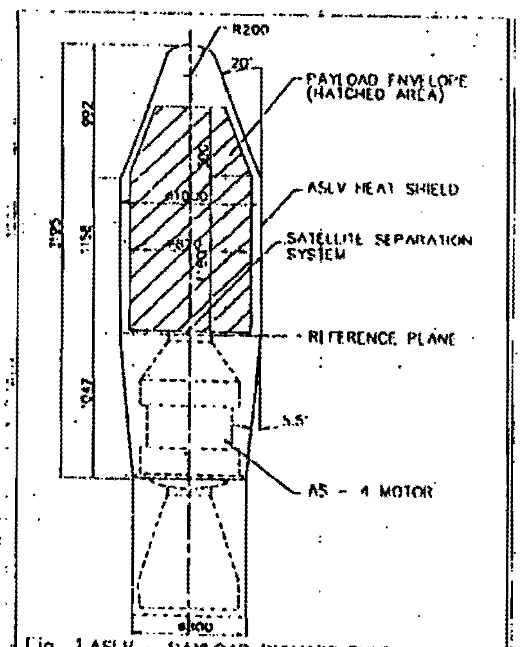


Fig. 1 ASLV - PAYLOAD DYNAMIC ENVELOPE

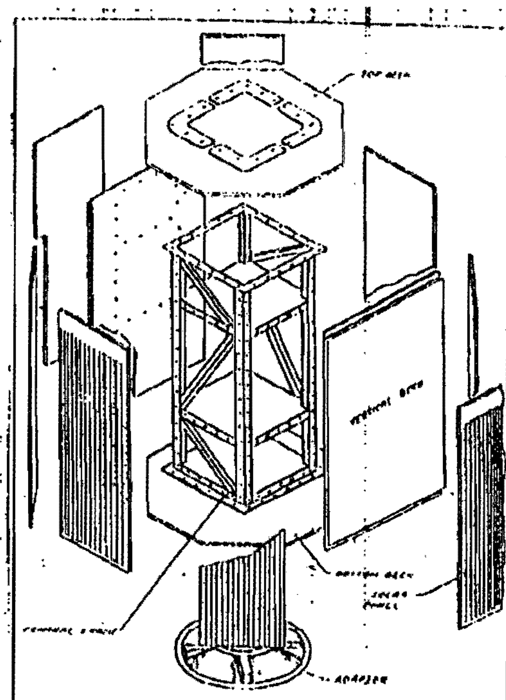


FIG. 2 EXPLODED VIEW OF SROSS-C STRUCTURE

4. SPACECRAFT DESIGN

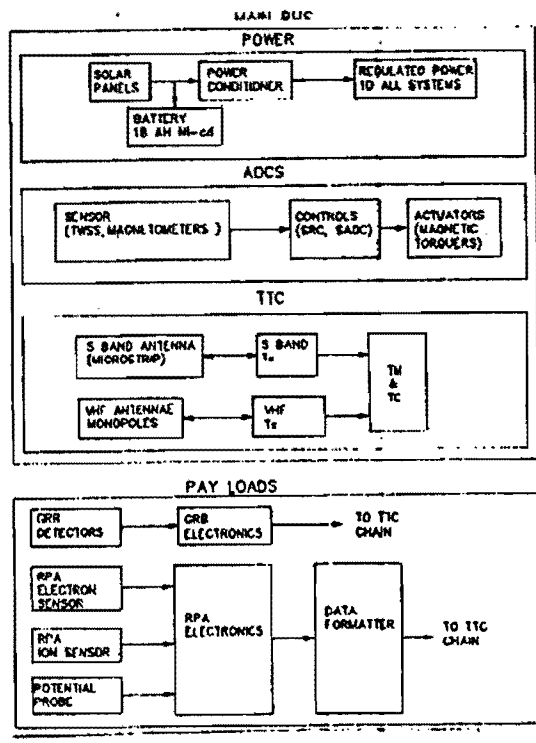
SROSS-C is the third satellite in this series which was put into an elliptical orbit by the third developmental flight ASLV-D3. The satellite carried two scientific payloads (i) the Gamma Ray Burst (GRB) Detectors, and (ii) the Retarding Potential Analysers (RPA). The GRB payload is an astronomy payload designed and developed by ISRO Satellite Centre (ISAC), Bangalore and the RPA payload is an aeronomy payload from the National Physical Laboratory (NPL), New Delhi. This satellite weighing 106.1 Kg is a spinner satellite realised under the full heritage of the proven hardware elements of the SROSS bus(Fig.3).

First the mission requirements were taken into consideration in order to draw the design of the overall configuration of the spacecraft. The GRB experiment requires that the field of view of its detectors should not be obstructed by the earth and also the coning about its view axis should be within 2 degrees. The RPA needed its sensors to be pointed along the positive roll axis at least within 5 degrees during each spin of around 2 to 5 rpm. The spacecraft was thus configured to be a spinner with its spin axis oriented normal to the orbital plane, GRB detectors mounted parallel to spin axis, and RPA detectors mounted perpendicular to spin axis.

Certain special requirements were also needed to be incorporated. Although the GRB detectors are scalar detectors, removal of the modulation effect of coning of its view axis required the spacecraft to be balanced about the maximum moment of inertia (MMI) axis. Since the launch vehicle any way requires the spacecraft to be balanced about the longitudinal axis, a full fledged computer simulation of the mechanical layout helped the spacecraft to satisfy both these requirements. The second special requirement was to design a good ground plane for the RPA experiment. This was achieved by means of a conductive Multi-Layer Insulation(MLI) with ITO coating tied to the structural reference at specified number of points with very thin wire mesh fixed additionally to the MLI surface. The third special requirement was to keep the solar panel strings at zero potential for most reliable operation of the RPA experiment. A typical logic scheme was hence implemented such that the entire spacecraft was supported by the battery for the limited period of operation of the RPA. Immediately after the suspension of this operation, the spacecraft switches back to the normal positive bus voltage operation. The fourth special effort was to save BSR/BSFR solar cell silver mesh interconnectors from erosion effects of atomic oxygen prevalent at such low earth orbits. The interconnectors were coated with special RTV compound and were qualified against degradation due to thermal cycles in space environment. A crude experiment was also devised in order to study such effects at low earth orbits by using two non-critical temperature sensors.

By and large, the overall design of the spacecraft has the common SROSS bus. The mechanical configuration is modular without the deployable solar panels. The thermal configuration is based on simplified 86 node analysis in order to keep the temperatures within allowable limits. The thermal system consists of passive elements like tapes, paints and MLIs in addition to a small number of electrical heaters for certain critical subsystems like the battery. A very judicious design is adopted since the solar aspect angle varies from 21 degrees to 159 degrees.

3 BLOCK DIAGRAM OF SROSS-C SATELLITE

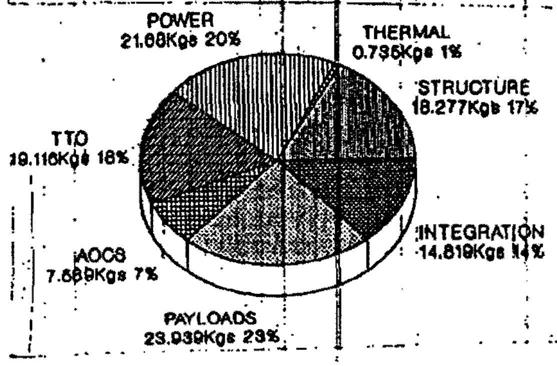


The primary power of 45W is generated by 1882 cell body mounted solar panels while an 18 AH Ni-Cd battery is used as the back up to supply power for peak loads and eclipse periods. Since the solar array is directly tied to the chemical battery, the array is designed to deliver power at 19.6 volts. In order to protect the battery against overdischarge, an emergency/normal logic scheme operates between 13.7 V and 15.6V. The raw bus is regulated using converter regulators to distribute power to subsystems at bus voltage of +5V, +15V ,-15V & +28V with redundancy.

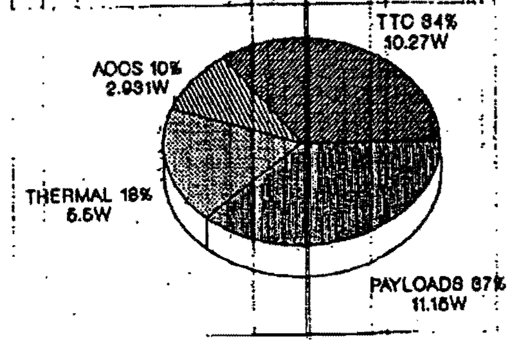
The house keeping telemetry subsystem has hot redundancy with a PROM based main unit backed by a microprocessor based redundant unit. The system has a 32 stage counter providing On Board Time (OBT) with a resolution of 1 msec. Main channel parameters are monitored at every 4 seconds, while sub channel parameters are monitored at every 32 seconds. Dwell mode logic is provided to monitor selected parameters at a faster rate in case of any contingency/ special requirement. The telecommand subsystem has hot redundancy also with a hardware decoding unit coupled to the VHF receiving chain and a microprocessor based decoding unit coupled to the S-band receiving chain. The sub-system is capable of providing on/off, date, time tagged and automatic commands in real time as well as in stored mode. The S-band transponder is used to transmit telemetry data in 20 dbm output mode and payload data in 30 dbm output mode through a transco switch, as well as receive telecommand and ranging signals in non-coherent and coherent modes respectively. The S-band TTC transponder is a standard 240/221 turn around ratio type transponder which is compatible with ISTRAC, ESA and NASA networks. The VHF links are provided in order to enhance operational reliability and for contingency. The S-band antenna consists of an array of 24 circularly polarised microstrip elements mounted on 8 printed circuit boards fixed all around the top deck in a belt array fashion giving an excellent omni directional pattern. The VHF antenna consists of 4 monopole elements mounted on four corners of the top deck of the satellite.

The Attitude and Orbit Control Electronics(AOCE) system has the electronics hardware in common, and software and actuators in difference for 3-axis stabilised and spin stabilised missions. Two torquers are used in order to carry out functions like spin rate control and spin axis orientation control as magnetic bias control for simpler missions like SROSS-C. A passive fluid-in-tube type nutation damper is also used for nutation damping functions. Three magnetometers are placed one on each axis of the satellite to provide spin rate and spin axis orientation information in a coarse manner. A twin slit sun sensor (TWSS) is used to provide the aspect angle information between the sun and the spin axis. The AOCE system is RCA 1802 microprocessor based and has full redundancy. For 3-axis stabilised missions like SROSS-1 and SROSS-2 however a 10 NM momentum wheel was used as the actuator for pitch axis control. A mass expulsion monopropellant hydrazine based RCS employing six numbers of 1N thrusters is used for SROSS-1, SROSS-2 and SROSS-C2 satellites for despin, orbit raising etc. Details of SROSS-C Weight & Power break-up is given in Figs 4(a) and 4(b).

4a. SROSS-C WEIGHT BREAKUP



4b. SROSS-C POWER BREAKUP



5. PAYLOAD DESIGN

5.1. Gamma Ray Burst Detection Payload: The GRB payload consists of a main and a redundant scintillation detectors viewed by separate photomultiplier tubes and powered by independant high voltage supplies. A common microprocessor based electronics system processes the signals from either of the detectors. Normally the main detector is kept on. The main detector consists of one 76 mm diameter and 12.5 mm thick CSI (Na) scintillator optically coupled to one EMI 9785 Na PMT. The redundant detector is also another CSI (Na) crystal and has diameter of 38 mm and thickness of 12.5 mm. It is viewed by one RCA 71510 tube. The scintillator is coupled to the PMT with DC-93500 potting compound. The processing electronics enables the measurement of temporal and spectral features of the bursts when the 100 - 1000 Kev photon counting rate exceeds a preset counting rate threshold stored onboard the satellite. The threshold itself is selectable through data command.

The instrument is designed to operate in six modes using a microprocessor supported by a memory bank of 64K bits. The first three modes are for burst search, detection and processing with different initial conditions. The fourth mode is for measurement of background gamma ray spectra for a total duration of about one orbit. The fifth mode is for short time calibration of the detectors when the satellite is in radio visibility. The sixth mode is for electronics instrument self check, when the satellite is in radio visibility. The experiment is intended to monitor celestial gamma ray bursts in the energy range 20 - 3000 Kev with 2 ms, 16 ms and 256 ms resolutions. The experiment is also configurable in a background mode to collect data on solar gamma rays and gamma ray background as a function of latitude in near earth space.

5.2. Retarding Potential Analyser: The RPA consists of one Electron Sensor, one Ion Sensor and one Potential Probe(PP) and a common processing electronics package. The Electron and Ion sensors are identical in construction except that Entrance grid in the electron sensor is electrically insulated from the sensor body. The PP is a passive probe meant to measure the potential of the spacecraft with respect to the ionospheric plasma. The Electron/Ion sensor consists of four mesh grids and one solid collector electrode. All grids are made of 100 by 100 count gold plated tungsten 1 mil wire mesh and have optical transparency as high as 95%. Each sensor uses a planar geometry and consists of a multigraded Faraday Cup having a solid collector plate. Electrons/Ions entering the sensor aperture pass through a region that is electrically segmented by a series of gold plated tungsten mesh grids called Entrance grid, Retarding grid, Suppressor grid before striking the collector. The current thus collected at the collector is of the order of picoamps to microamps. This current is amplified and measured by linear automatic gain ranging Electrometer Amplifier. The characteristic curve of the collector current vs retarding voltage(I-V) is used to derive information of Electron/Ion density, temperature and flux set against the satellite potential.

The processing electronics system is designed using one RCA 1802 microprocessor as the main subsystem and one PROM as the redundant subsystem. The Ion sensor operates in 3 modes while the electron sensor operates in 4 modes.

6. FABRICATION AND TESTING

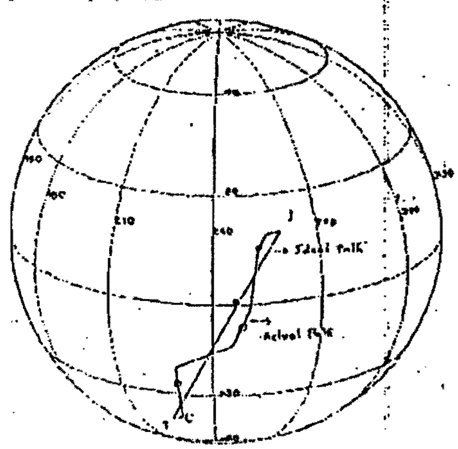
The design of various subsystems has gone through test and evaluation both at subsystem and system levels at the qualification stage (ETM model). Further all flight subsystems have passed through the acceptance level hot and cold, thermovac, and vibration tests before getting integrated onto the spacecraft. The totally assembled and integrated spacecraft was subjected to shock test, acoustic test and 21 day thermovac test before it was shipped to the launch site at SHAR near Madras, packed in a special transportation container. The reliability and quality measures that are adopted for the spacecraft start at screening of components and end at prelaunch checks at the launch site. At each stage of development, fabrication, and testing log books are maintained with a view to ascertaining any anomalous behaviour of the spacecraft systems at any stage.

7. LAUNCH AND ON-ORBIT OPERATION

SROSS-C was launched atop ASLV-D3 on May 20,1992 at 6.00 hrs IST from SHAR. The powering of the satellite was done at T-6hrs. Initialisation of the spacecraft for the required launch configuration was completed at T-5 hrs 24 min. Solar array simulator was withdrawn 5 minutes before lift-off. The spacecraft was injected at T+501 secs spinning at 78 rpm about its longitudinal axis. The apogee and perigee heights were determined to be 268Km & 400Km within 30 minutes after its separation from the vehicle.

Fig.5

SPIN AXIS ORIENTATION CONTROL FOR SROSS-C



INI ATD ORBIT NO. - 00058	R.A = 259.59	DEC =	19.82
CUR ATD ORBIT NO. - 00071	R.A = 227.59	DEC =	-47.59
TAR ATD ORBIT NO. - 00071	R.A = 224.39	DEC =	-43.97
SUN POSITION :	R.A = 60.45	DEC =	20.67

Downlink and uplink were established both in VHF and S-band frequencies. It was in the 9th orbit that the spin rate control was initiated to bring down the spin rate to 5.7rpm. At orbit 50, the SRC was completed and the SOAC was initiated at orbit 55. Attitude was continuously monitored at every visible pass. At orbit 70 it was found that the angular separation between the spin axis and the negative orbit normal of orbit 90 was about 7.75 degrees. It was hence concluded that the angle between the spin axis and the negative orbit normal of orbit 70 was within 3degrees after taking the orbit regression rate into consideration. Fig.5 shows the contour of the SAOC operation. At the end of orbit 71, MBC was switched on in order to counteract the orbit regression rate.

8. CONCLUSION

SROSS-C satellite completed only 888 orbits before reentry on July 14, 1992 due to the lower perigee. Nevertheless, the GRB payload registered 57 triggers till reentry. The RPA payload got 134 sets of useful data. Out of the few interesting events the GRB payload registered, orbit 377 is unique in the sense that the temporal profile of the 100-1024Kev counting rate from To -10s to To + 10s, plotted at 256ms resolution, is a near symmetric event having a rise time of about 512ms and a duration of about 2.5sec. The temporal profile of the 20-1024 Kev count rate is plotted with a resolution of 16 ms. One knows that the initial burst followed by three spikes of decreasing intensity is characteristic of many celestial gamma ray bursts.

The RPA payload similarly found some special events like plasma holes in the equatorial region. Simultaneous observations of F-region irregularities on RPA, ionosonde and MST radar have confirmed interest in analysing full data over the equator on two interesting occasions. The reportings are yet to be established.

Not withstanding the above mentioned events of scientific interest, what is more important to ISRO is the design of the SROSS bus which has proved its mettle in orbit. The common bus thus adopted for a variety of missions proves to be our work horse in small satellite services based on the development experience of SROSS-1 and SROSS-2, and also the successful on-orbit operation of SROSS-C. To conclude SROSS adaptability which is the key to the success of a small satellite series.

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